

UNITED STATES PATENT APPLICATION FOR:

METHOD FOR PLANARIZING
ORGANOSILICATE LAYERS

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Field of the Invention

Description of the Background Art

[0003] In such integrated circuit fabrication processes, it is necessary for the dielectric layers to have a flat surface (e. g., planar surface topography). This is because it is difficult to image and pattern material layers applied over non-planar surfaces using conventional photolithographic techniques.

[0004] Chemical mechanical polishing (CMP) processes have been developed to produce surface topographies that are sufficiently planar to satisfy the demands of conventional photolithographic techniques used in integrated circuit fabrication processes. CMP processes use a chemical polishing slurry in conjunction with mechanical energy to planarize the surface of a material layer.

[0005] As the dimensions of the integrated circuit components are reduced, the choice of material used to fabricate such components becomes increasingly critical. For example, when the distance between adjacent metal interconnects and/or the thickness of the dielectric material has sub-micron dimensions, capacitive coupling potentially occurs between such interconnects. Capacitive coupling between adjacent metal interconnects may cause cross talk and/or resistance-capacitance (RC) delay which degrades the overall performance of the integrated circuit.

[0006] In order to prevent capacitive coupling between adjacent metal interconnects, low dielectric constant (low k) insulating materials (e. g., dielectric constants less than about 4.5) are needed. Suitable low k dielectric materials may include organosilicate materials. However, organosilicate materials are prone to form defects, such as scratches and cracks when subjected to chemical mechanical polishing (CMP). Such defects are undesirable because they may cause integrated circuit malfunction.

[0007] Therefore, a need exists in the art for a method of planarizing organosilicate material layers.

SUMMARY OF THE INVENTION

[0008] A method for planarizing an organosilicate layer is provided. The organosilicate material layer is planarized using a slurry in conjunction with a chemical mechanical polishing (CMP) process. The slurry comprises an abrasive material dispersed in a suitable solvent. The slurry preferably has a pH greater than about 9. The abrasive material preferably has an average particle size greater than about 35 nm (nanometers).

[0009] The organosilicate material layer may be planarized using the slurry in conjunction with a CMP process. In one CMP process, a substrate having an organosilicate layer is placed in contact with a polishing pad on a rotatable

platen. The polishing pad has the slurry thereon. The organosilicate material layer is planarized by moving the substrate and platen relative to one another.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

[0011] FIG. 1 depicts a schematic illustration of a chemical mechanical polishing (CMP) apparatus that can be used for the practice of embodiments described herein; and

[0012] FIGS. 2a-2b depict schematic cross-sectional views of a substrate at different stages of integrated circuit fabrication.

DETAILED DESCRIPTION

[0013] Embodiments described herein relate to a planarization process that may be performed using a chemical mechanical polishing (CMP) process system, such as, for example, the Mirra® CMP System, available from Applied Materials, Inc., Santa Clara, California. Details of the Mirra® CMP System are described in commonly assigned U.S. Patent No. 5,738,574, entitled, "Continuous Processing System for Chemical Mechanical Polishing," which is herein incorporated by reference. Although, the CMP process system described herein is illustrated utilizing the Mirra® CMP System, other CMP systems which may be used to perform chemical mechanical polishing are also contemplated.

[0014] FIG. 1 is a schematic perspective view of a chemical mechanical polishing system 20. The polishing system 20 includes a lower machine base 22 with a table top 28 mounted thereon and a removable outer cover (not

shown). The table top 28 supports a series of polishing stations 25a, 25b, 25c as well as a transfer station 27.

[0015] The transfer station 27 performs multiple functions, such as, for example, receiving individual substrates 10 from a loading apparatus (not shown), washing substrates, and loading/unloading substrates to/from carrier heads 80.

[0016] Each polishing station 25a, 25b, 25c includes a rotatable platen 30 having a polishing pad 100, 110 disposed thereon. The platen 30 may be a rotatable aluminum or stainless steel plate connected to a platen drive motor (not shown).

[0017] The polishing stations 25a, 25b, 25c may optionally include a pad conditioner 40. The pad conditioner 40 comprises a rotatable arm 42 holding an independently rotating conditioner head 44 and an associated washing basin 46. The pad conditioner 40 is used to maintain the condition of the polishing pad 100, 110.

[0018] The polishing stations 25a, 25b, 25c may also include a slurry/rinse arm 52 having two or more supply tubes 53 to provide one or more chemical slurries and/or water to the surface of the polishing pad 100, 110. The slurry/rinse arm 52 delivers the one or more chemical slurries in amounts sufficient to cover and wet the entire polishing pad surface 100, 110. Each slurry/rinse arm 52 also includes several spray nozzles (not shown) that can provide a high-pressure fluid rinse to the polishing pad at the end of each polishing and/or conditioning cycle.

[0019] Two or more intermediate washing stations 55a, 55b, 55c may optionally be positioned between adjacent polishing stations 25a, 25b, 25c to clean a substrate 10 as it passes from one polishing station to the next.

[0020] A rotatable multi-head carousel 60 is positioned above the lower machine base 22. The carousel 60 includes four carrier head systems 70a, 70b, 70c, 70d. Three of the carrier head systems function to hold substrates 10 against the polishing pads 100, 110, during a polishing process. The fourth

carrier head system functions to move substrates 10 to/from the transfer station 27.

[0021] The carousel 60 is supported by a center post 62, and is rotated about a carousel axis 64 by a motor assembly (not shown) located within the machine base 22. The center post 62 also supports a carousel support plate 66 and a cover 88.

[0022] The four carrier head systems 70a, 70b, 70c, 70d are mounted on the carousel support plate 66 at equal angular intervals about the carousel axis 64. The center post 62 permits the carousel motor (not shown) to rotate the carousel support plate 66 and orbit the carrier head systems 70a, 70b, 70c, 70d about the carousel axis 64.

[0023] Each carrier head system 70a, 70b, 70c, 70d includes a carrier head 80. A carrier drive shaft 78 couples a carrier head rotation motor 76 to each carrier head 80, so that the carrier head 80 can be rotated about its own axis. In addition, each carrier head 80 may be oscillated laterally in a radial slot 72 formed in the bottom of the carousel support plate 66.

[0024] The carrier head 80 is used to hold substrates 10 against the polishing pads 100, 110, by evenly distributing a downward pressure across the back surface thereof. This downward pressure transfers torque from the drive shaft 78 to the substrates 10, and ensures that the substrate 10 does not slip out from beneath the carrier head 80 during the polishing process.

Chemical Mechanical Polishing Slurry for Planarizing Organosilicate Material Layers

[0025] A polishing slurry suitable for planarizing an organosilicate material layer is described. Organosilicate materials comprise silicon (Si), carbon (C), oxygen (O), and hydrogen (H). The general formula for an organosilicate material is $\text{Si}_w\text{O}_x\text{C}_y\text{H}_z$, where w, x, y, and z are integers that define the ratio of silicon, oxygen, carbon, and hydrogen in the material layer.

[0026] The polishing slurry for planarizing the organosilicate material comprises an abrasive material dispersed in a suitable solvent. The abrasive material is preferably insoluble in the solvent.

[0027] Water is an example of a suitable solvent for the abrasive material. Suitable abrasive materials may include, for example, silica (SiO_2), aluminum oxide (Al_2O_3), zirconium oxide (ZrO_2), titanium oxide (TiO_2), and combinations thereof, among others.

[0028] The average particle size for the abrasive material is preferably greater than about 35 nm (nanometers). Additionally, the concentration of abrasive material in the slurry should be about 10% by weight to about 60% by weight.

[0029] Polishing rates of organosilicate material layers polished using the polishing slurry described herein are increased by increasing the pH of the slurry. The polishing slurry should preferably have a pH greater than about 9.

[0030] The pH of the polishing slurry may be varied by adding a source of hydroxyl ions to the slurry. Suitable sources of hydroxyl ions may include potassium hydroxide (KOH), ammonium hydroxide (NH_4OH), sodium hydroxide (NaOH), magnesium hydroxide (MgOH), calcium hydroxide (CaOH), and combinations thereof, among others.

[0031] The source of hydroxyl ions is also believed to prevent pH drift in the slurry during the polishing processes. pH drift is undesirable because it may result in inconsistent polishing rates during the polishing process.

[0032] Additionally, the polishing slurry may optionally include one or more materials selected from the group consisting of chelating agents, buffers, oxidizers, and corrosion inhibitors. Suitable chelating agents may include, for example, ethylenediaminetetraacetic acid, ethylenediamine, and methylformamide, among others. Suitable oxidizers may include, for example, hydrogen peroxide and ferric nitrate, among others. Suitable corrosion inhibitors may include, for example, benzotriazole, mercaptobenzotriazole, and 5-methyl-1-benzotriazole, among others. Suitable buffers may include

organic or inorganic acids such as, for example, acetic acid, phosphoric acid, and nitric acid, among others.

Example 1 (Comparative)

[0033] An aqueous polishing slurry comprising about 30% by weight silica particles having an average particle size of about 20 nm (nanometers) was prepared. The aqueous slurry had a pH of about 2.5, buffered with ammonium hydroxide (NH₄OH).

[0034] An organosilicate material layer formed on a substrate was planarized using the aqueous polishing slurry described above in conjunction with a CMP process. The organosilicate layer was planarized by providing the aqueous slurry to a Mirra® CMP system (commercially available from Applied Materials, Inc., Santa Clara, California), having a IC 1400 polyurethane polishing pad therein (commercially available from Rodel Inc., Newark, Delaware). The organosilicate layer was polished by contacting it with the polishing slurry using a polishing pressure of about 4 psi (pounds/square inch) and a platen speed of about 0.8 m/s (meters/second). The polishing rate for the organosilicate layer was about 100 Å/min.

Example 2

[0035] An aqueous polishing slurry comprising about 30% by weight silica particles having an average particle size of about 35 nm (nanometers) was prepared. The aqueous slurry had a pH of about 10, buffered with ammonium hydroxide (NH₄OH).

[0036] An organosilicate material layer formed on a substrate was planarized using the aqueous polishing slurry described above in conjunction with a CMP process. The organosilicate layer was planarized by providing the aqueous slurry to a Mirra® CMP system (commercially available from Applied

Materials, Inc., Santa Clara, California), having a IC 1400 polyurethane polishing pad therein (commercially available from Rodel Inc., Newark, Delaware). The organosilicate layer was polished by contacting it with the polishing slurry using a polishing pressure of about 4 psi (pounds/square inch) and a platen speed of about 0.8 m/s (meters/second). The polishing rate for the organosilicate layer was about 400 Å/min.

Example 3

[0037] An aqueous polishing slurry comprising about 30% by weight silica particles having an average particle size of about 35 nm (nanometers) was prepared. The aqueous slurry had a pH of about 11, buffered with ammonium hydroxide (NH₄OH).

[0038] An organosilicate material layer formed on a substrate was planarized using the aqueous polishing slurry described above in conjunction with a CMP process. The organosilicate layer was planarized by providing the aqueous slurry to a Mirra® CMP system (commercially available from Applied Materials, Inc., Santa Clara, California), having a IC 1400 polyurethane polishing pad therein (commercially available from Rodel Inc., Newark, Delaware). The organosilicate layer was polished by contacting it with the polishing slurry using a polishing pressure of about 4 psi (pounds/square inch) and a platen speed of about 0.8 m/s (meters/second). The polishing rate for the organosilicate layer was about 600 Å/min.

Example 4

[0039] An aqueous polishing slurry comprising about 30% by weight silica particles having an average particle size of about 70 nm (nanometers) was prepared. The aqueous slurry had a pH of about 10, buffered with ammonium hydroxide (NH₄OH).

[0040] An organosilicate material layer formed on a substrate was planarized using the aqueous polishing slurry described above in conjunction with a CMP process. The organosilicate layer was planarized by providing the aqueous slurry to a Mirra® CMP system (commercially available from Applied Materials, Inc., Santa Clara, California), having a IC 1400 polyurethane polishing pad therein (commercially available from Rodel Inc., Newark, Delaware). The organosilicate layer was polished by contacting it with the polishing slurry using a polishing pressure of about 4 psi (pounds/square inch) and a platen speed of about 0.8 m/s (meters/second). The polishing rate for the organosilicate layer was about 950 Å/min.

Example 5

[0041] An aqueous polishing slurry comprising about 30% by weight silica particles having an average particle size of about 70 nm (nanometers) was prepared. The aqueous slurry had a pH of about 11, buffered with ammonium hydroxide (NH₄OH).

[0042] An organosilicate material layer formed on a substrate was planarized using the aqueous polishing slurry described above in conjunction with a CMP process. The organosilicate layer was planarized by providing the aqueous slurry to a Mirra® CMP system (commercially available from Applied Materials, Inc., Santa Clara, California), having a IC 1400 polyurethane polishing pad therein (commercially available from Rodel Inc., Newark, Delaware). The organosilicate layer was polished by contacting it with the polishing slurry using a polishing pressure of about 4 psi (pounds/square inch) and a platen speed of about 0.8 m/s (meters/second). The polishing rate for the organosilicate layer was about 3080 Å/min.

Example 6

[0043] An aqueous polishing slurry comprising about 22% by weight silica particles having an average particle size of about 70 nm (nanometers) was prepared. The aqueous slurry had a pH of about 11, buffered with ammonium hydroxide (NH₄OH).

[0044] An organosilicate material layer formed on a substrate was planarized using the aqueous polishing slurry described above in conjunction with a CMP process. The organosilicate layer was planarized by providing the aqueous slurry to a Mirra® CMP system (commercially available from Applied Materials, Inc., Santa Clara, California), having a IC 1400 polyurethane polishing pad therein (commercially available from Rodel Inc., Newark, Delaware). The organosilicate layer was polished by contacting it with the polishing slurry using a polishing pressure of about 4 psi (pounds/square inch) and a platen speed of about 0.8 m/s (meters/second). The polishing rate for the organosilicate layer was about 2100 Å/min.

Example 7

[0045] An aqueous polishing slurry comprising about 30% by weight silica particles having an average particle size of about 70 nm (nanometers) was prepared. The aqueous slurry had a pH of about 11, buffered with potassium hydroxide (KOH).

[0046] An organosilicate material layer formed on a substrate was planarized using the aqueous polishing slurry described above in conjunction with a CMP process. The organosilicate layer was planarized by providing the aqueous slurry to a Mirra® CMP system (commercially available from Applied Materials, Inc., Santa Clara, California), having a IC 1400 polyurethane polishing pad therein (commercially available from Rodel Inc., Newark,

Delaware). The organosilicate layer was polished by contacting it with the polishing slurry using a polishing pressure of about 4 psi (pounds/square inch) and a platen speed of about 0.8 m/s (meters/second). The polishing rate for an organosilicate layer was about 3300 Å/min.

Planarization of an Organosilicate Intermetal Dielectric Material Layer

[0047] FIGS. 2a-2b illustrate schematic cross-sectional views of a substrate at different stages of an integrated circuit fabrication incorporating a planarization process. In general, the substrate 200 refers to any workpiece on which processing is performed, and a substrate structure 250 is used to denote the substrate 200 together with other material layers formed thereon. Depending on the specific stage of processing, the substrate 200 may correspond to a silicon wafer, or other material layer that has been formed on the silicon wafer.

[0048] FIG. 2a, for example, illustrates a cross-sectional view of a substrate structure 250, having conductive metal features 202 and an organosilicate layer 204, thereon. The organosilicate layer 204 is formed between and on top of each conductive metal feature 202. The organosilicate layer 202 is an intermetal dielectric for the conductive metal features 202.

[0049] The conductive metal features 202 may be formed of a metal (e.g. copper (Cu), aluminum (Al), tungsten (W)). The conductive metal features 202 have aspect ratios greater than about 4:1. As used in this disclosure the term aspect ratio is defined as the ratio of the height of the metal feature to its width.

[0050] The organosilicate layer 204 may be formed using conventional processes such as, for example, chemical vapor deposition (CVD) techniques, spin-coating techniques, sol-gel techniques, and dip coating techniques, among others. The thickness of the organosilicate layer 204 is variable, depending upon the specific stage of integrated circuit fabrication.

Typically, the organosilicate layer 204 has a thickness of about 1,000 Å to about 10,000 Å.

[0051] Referring to FIG. 2b, the organosilicate layer 204 is planarized. The organosilicate layer 204 is planarized using a polishing slurry in conjunction with a CMP system similar to that shown in FIG. 1. The polishing slurry may be, for example, as described above in any of Examples 2-8. Suitable polishing conditions includes a polishing pressure of about 1 psi to about 14 psi, and a platen speed of about 0.1 m/s to about 2.0 m/s.

[0052] Although several preferred embodiments, which incorporate the teachings of the present invention, have been shown and described in detail, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.

TECHNOLOGICAL